1
Introduction

1.1 BACKGROUND

The study is set in the Rajasthan, a state in western India, occupying an area of 342,239 km^2. It covers more than 10.4% of total geographical area of India. Further, it is located within 23º03′–30º12′N and 69º9′–78º17′E [Hussain *et al*., 2014]. The experiments and surveys presented in this thesis are based in Jodhpur is one of the districts of western Rajasthan (comprising Jodhpur, Bikaner, Barmer and Jaisalmer district) [CGWB, 2011]. Rajasthan state is bound by Pakistan in the west, Punjab, Haryana and Uttar Pradesh in the north, and Madhya Pradesh in the east and by Gujarat in the south, respectively. The Thar Desert (Rajasthan, India) covers thirty-two percent of Rajasthan [Hussain *et al*., 2014]. It is one of the most inhospitable regions of the world [CGWB, 2011]. This desert is the most densely populated and continuously inhabited for over 1200 years [Hussain *et al*., 2014]. The hills and plateaus illustrated in Figure 1.1 are of the Aravalli and Vindhya [GSI, 2011; Upadhyaya, 2014]. Traditionally people in this region depend on local resource utilization. The people of this region made effective resource management approaches to sustain human and livestock populations in this region [CGWB, 2011].

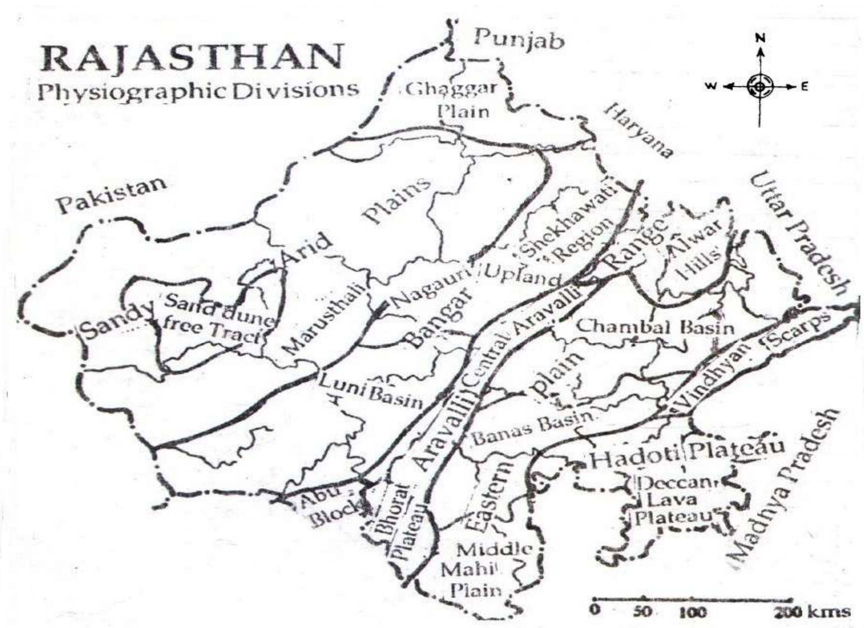

Figure 1.1: The map of Rajasthan India [Upadhyaya, 2014]

In India, traditional societies based themselves with systemic concept of dwelling around and protecting sacred groves for the respect of ancestral thoughts and ecological biodiversity or aspects with functional advantage [Ramakrishnan, 2001]. Further, the Bharti tirtha aphorism in the 'Parisista' of Atharva Veda, depicting stories of the deity Krishna provide the value of π upto an accuracy of 31 decimal places [Ramamurthy, 2014]. The monsoon climatic system of India and its direction were depicted in the form of a poem-based drama by Kalidasa, an Indian poet in the seventeenth century [Westra, 2012; Wilson, 1842]. The UN recently exclaimed to observe these hidden traditional systems and technologies in a new way rather pushing them off as archaic [Bigas *et al*., 2009]. Are engineering aspects embedded within the traditional devices and materials of daily use in rural India? Therefore, this question probes the sustenance and even renascence of these in this twenty-first century [Zafar, 2008]. To answer the question, three locally engineered material structures were manufactured, studied, and analyzed in this thesis. These were the traditional aesthetic indoor shelf, off-white earthen pots for cooling water, and the local clay ceramic water filter respectively. These are supposed to depict the technical design dialogue around technology, community, and water.

The top-down approaches to research on local environment-based technologies appreciate scientific subject-based knowledge as supreme [Tsing *et al*., 2005]. This lends a nature of ignorance toward processes being carried out at a specific location because of its ecology and its societal adaptation [Smith 2008]. The top-down approach therefore, may alienate local traditional knowledge on environmental resources and their knowledge of managing these resources [Smith, 2008]. Therefore, a modified top-down yet bottom-up research approach appreciating and incorporating traditional material technology, local knowledge and inherited skills by members of specific communities are considered pertinent in this dissertation [Smith, 2008]. The communities have lack of scientific knowledge on the actual processes or procedures they perform due to cultural requirements [Carr, 2002].

Santhi (Dailect based *Sansi*) community is a seasonally nomadic community in Barmer, Rajasthan, India [Gusain, 2002]. They use horse (*Marwari* breed) dung as a medicinal material as well as construction material. Horse dung can be categorized as an animal waste and hence an organic waste. The knowledge about the properties of horse dung has been transferred from generation to generation in this community. Due to its medicinal nature and its influence on the health of the household this knowledge was basically inherited by the women of the *Santhi* or *Sansi* community. Women sustained the traditional knowledge by inculcating traditional art of making aesthetic shelves within the household. Here, women mixed an equal volume of the Equus dung and soil to make a farrago. Water is mixed with this farrago to provide with a sticky composite. This composite was pasted directly on mud walls and held by bamboo twigs protruding at equal lengths from the wall surface at equal distances. Here the rural definition of equal volumes was defined by one fist full of horse dung and one fist full of soil [Satankar *et al*., 2018]. This traditional knowledge existed in Marwar region only.

The horses in this region of India were of mostly *Marwari* breed and ecologically inhabited in arid western Rajasthan [Livestock Census, 2012]. As per national livestock census in 2012, the equine populace in India is approximate 1.14 million which includes steeds and horses 55%, donkeys 17% and 28% jackasses [Livestock Census, 2012]. Ninety-eight percent populace of these Equidae provides occupation to the landless, little, and minimal agriculturists through the usage of equines in carts and carriages. The rest two percent of the equine populace is claimed by top segments of society and utilized for diverse purposes e.g. polo, riding, and so forth for national security reason by military and paramilitary forces [Sheik, 2016].

The above discussion is an adjunct aspect of the need to conserve Equus animal in order to sustain the structural and medicinal applications of Equus dung. Therefore, the use of horse dung in building construction can be seen as a solid waste management process, which culturally immingle with traditional knowledge in constructing structures. This can be categorized as a process of the construing the traditional concepts "soft power" which cultural Rajasthan caters to its technological visitors [Nye, 2017]. However, this technology is almost obsolete and requires its revival and sustenance. The sustenance feasibility of this indigenous technology is the promotion of modern 'soft power' initiatives in the various fields including that of construction in rural areas in India [Tharoor, 2016]. In a broad sense, modern technologies will eventually beleaguer all the archaic, traditional practices and design processes in Indian villages [Groenfeldt, 2003; Kala *et al*., 2006]. Therefore, strong re-engineering and analysis of traditional devices and processes are needed to confirm the sustainability of traditional know-how of communities in India [Singh *et al*., 2010]. The know-how, local innovations, and cultural practices of local communities of India representing traditional lifestyles are eroding away with time. The scarcity of research to establish unfounded traditional methods, material and practices lead to this erosion. This thesis suggests that a huge technological know-how was being practiced in a systematic manner to sustain the processes and procedures which is merely hidden under the garb of culture and traditional practices.

The knowledge of carbon footprint by a product and its ill-effects on the environment has permeated to all people within the economic pyramid [Turner, 2014]. Cement is one of the most discussed and cited materials enshrouded with a large carbon footprint tag [Turner, 2014]. In order to reduce cement use, the world is looking forward towards the design of sustainable, green, efficient eco-friendly material [Allwood *et al*., 2011]. Therefore, identification of long-lasting processes and materials, re-use of human, animal, agricultural, and industrial waste and researching archaic materials have to be done.

The total municipal solid waste generation (biodegradable waste, recyclable waste, inert waste matters, domestic hazardous waste, and toxic waste) of India ranges from 65-69 million tons per annum [Annepu, 2012; Joshi and ahmed, 2016]. Insensitive project implementation and lack of research have led to open dumping of solid waste in India [Annepu, 2012; Kota, 2013]. On other hand animal dung accounts for approximately 74% of the rural waste produced per year in India [Hosseti, 2006]. Animal dung is considered a solid waste containing organics and water [Pappu *et al*., 2007]. Apart from use in biogas production and as a fertilizer, animal excreta mainly cow dung and horse urine are used as a soil stabilizer in traditional construction [SKAT, 2008]. Further, cow dung is being used as a filler material in glass structures to modify thermal insulation attributes of the glass fiber [Venkatarama, 2009]. The major aspect is that soil and animal dung can be easily related to the pre-historic daub [Shaffer, 1993]. Recently soil stabilized with cow dung was cured to form a building material with comparatively higher compressive strength and lower weight than clay bricks [Haas Business School, 2009]. Therefore, animal dung forms an easily and locally available additive material organic that may help vary the fracture toughness and thermal insulation capacities of construction materials. This may also help to manage a part of the solid waste generated.

In the past, every house in urban or rural at Jodhpur used to have an earthen pot for cooling and storing the drinking water; but now with the increase in modern technology, people have switched to refrigerator which has reduced market for water pots impacting potters economically [Iqbal, 2017]. Jodhpur has a rural and urban population of 65.7 and 34.3 percentages respectively of the total population [Chandramouli, 2011]. The maximum and minimum temperature range from 47.8 °C and 4.2 °C respectively while humidity around 40 to 46% [Nahar *et al*., 2003]. The annual normal rainfall of the district is 313.7 mm. Jodhpur, which falls under the semi-arid areas neighboring the Thar desert have substantially poor rainfall and in summers humidity falls [Nahar *et al*., 2003; Aimiuwu, 1992]. Fetching water, its storage and cooling is a challenge in this arid zone when it is also economically backward [Chandramouli, 2011]. This is also a reason why local clay water jars (off-white) are popular in the arid rural area of this region since decades [Roux, 2015]. The raw materials for producing these jars are soil and sawdust. These off-white pots are again manufactured by sintering of clayey soil, animal dung, and saltpetre or "*kalmishora*" (in *Marwari* dialect) mixture [Banerjee, 2016].

Thatched house walls, natural material flooring, and water pots to maintain a low temperature in the summer has been used at households in arid areas [Olorumaiye, 1998]. Ambient heat is used to evaporate the porous material surface moisture in the process. This means latent heat gain by the moisture or water molecules assuming an adiabatic process [Olorumaiye, 1998]. Earthen pots were an important part of Indian civilization, these pots were widely used for cooking, storing grains for a year, water storage since the beginning of social living. These products were manufactured from variable quantities of soil and organic material immingled in presence of water. For generations, earthen pots or *matkas* have been used to store water and keep it cool in Jodhpur and the Thar desert. Materials (liquids) stored in clay vessels are cooled to about 10 °C and 14 °C and is said to have a refreshing flavor. The arid environment of Jodhpur causes human discomfort which can be allayed using methods of evaporative cooling [Nahar *et al*., 2003]. That is the reason the sale of these earthen pots is at peak at Jodhpur in summer [Banerji, 2016].

Water is an essential commodity for human and animal life [Adolph, 1947]. Rajasthan does not have major piped facilities and has areas where economic water scarcity marries physical water scarcity in Rajasthan [Plappally and Lienhard, 2013]. Biological contamination of drinking water resources in rural areas is a major issue in Rajasthan [Suthar, 2011]. Recent studies show a farrago of pathogenic bacteria, viruses, fungi, protozoa mycobacteria and helminths in local drinking water resources in Rajasthan [Suthar, 2011]. From the present scenario of localized water availability and un-piped settlements across Rajasthan, a point-of-use technology is required to be established for a safe drinking water treatment program in this area [Suthar *et al*., 2009]. The ceramic water filter proposed by the "Potters for Peace" (a non-governmental organization from Nicaragua) can be one of the solutions on rural drinking water treatment [Lantagne, 2001]. The ceramic water filters are being used for household water treatment at several locations around the world and was categorized as sustainable [Plappally, 2010].

The development of the ceramic water filter in Rajasthan acknowledges and supports the requirement of safe drinking water program and the active participation of potters with traditional clay baking knowledge. The aim is to promote household traditional pottery manufacturing practices, learning new skills to conservation or effective utilization of related resources for promoting an indigenized point-of-use drinking water treatment device. For performing this indigenization and re-engineering "Potter for Peace" technology for suiting household production procedure may follow a technical interrogation and participatory approach [Valdes, 2008].

A stark similarity in the initial processing of the immingle to manufacture the filter and composite for aesthetic shelves in Marwar region is worth analyzing. Secondly potter communities in the region work in their own households from ages [Roux, 2015]. Introducing a new technology with a variable material functionality is a challenge due to the societal inertia while working on a novel concept. Thirdly in order to introduce this new technology amongst the rural potters, help is to be derived from one of their own baking technologies which need not be taught to them. The potters in Jodhpur district use traditional cylindrical open draught furnaces for baking their claywares [Roux, 2015]. An elaborated discussion of sintering using open draught furnace, the geometrical arrangement of claywares, heating rate, and time for sintering will be required to shed light on the quality of ceramic filter production. Efficacy of these sintered bodies to provide microbe free drinking water at an optimal rate needs to be enumerated.

1.2 OBJECTIVES

The major objectives of this thesis are:

Investigate the technological principles responsible for the sustenance of use of horse dung (animal waste) towards the construction of aesthetic indoor shelves within "*Santhi* (*sansi*) community" households in the rural area of western Rajasthan. The investigation of strength of these structures, and environmental influences will be emphasized.

Clay and organic materials have been used to produce water storage pots in western Rajasthan for ages. Off-white colorization has been regarded to be the traditional reason for the sustenance of these pots in this area [Roux, 2015]. Salt addition has been practiced and potters simply taste the soil to infer if the soil is salty or not [Roux, 2015]. Technological reason has not surfaced yet for the sustainability of these water pots; therefore, this study will enumerate the material properties as well as functional efficacy.

Further, a case is discussed combining the scientific explanations from the experimental results of material properties determined while solving the first two cases. Here the scientific explanations and management studies were hidden under the influence of ethnographic aspects. The functionality of the locally manufactured clay ceramic water filtration device (G-filter) and the traditional household pottery management and baking process are studied. The main idea behind this work is to sustain traditional skill of communities and to reflect on the hidden technological aspects for their sustenance.

1.3 SCOPE OF WORK

The problems identified herein are an outcome of close observation and need to understand local material behavior, inherited traditional knowledge systems, and their utility in arid locations in western India. An effort to correlate the similarity in use of a specific soil and organic mixture irrespective of distinct functional and structural viability is to be carried out. The investigations are supposed to also proclaim unknown technical and scientific knowledge within these traditionally functional and structural materials. The studies will also find reasons of societal importance of this technology and devices in manufacture of newer functional ceramics. Sustainability and reliability aspect of technologies is studied by understanding the physics behind the material processing. Thus, there should be a standard technological framework with which generally recognized community knowledge is brought in as a scientific know-how.

The thesis deals with the composites and its related ceramics materials. The composites considered here are of simple soil, for example clay and organic waste (animal waste and sawdust). Analysis of the physical, microstructure, and functional properties of these composites and ceramics of use in western Rajasthan, India is performed.

1.4 OUTLINE OF THE CHAPTERS

Chapter-2 covers a detailed literature review on rural housing. It Identifies various aspects of materials and construction methodologies popular in rural India. Sintering methods and characteristics of the frustum shaped clay ceramic filters used around the world has also been discussed. It enumerates experimental methods and tests used in subsequent chapters to verify various physical and chemical properties. This chapter also outlines the stochastic multi-parameter framework developed for modeling heterogeneous aspects of various materials and processes dealt in chapter 3, 4 and 5.

Chapter-3 provides theoretical and experimental analysis of bio-composite manufactured from local clay and organic material (horse dung). The chapter reveals the physical and structural properties involved in the aesthetic structures used by the *Santhi* Community of western Rajasthan. The chapter also provides a novel mathematical framework on modeling the density, thermal conductivity, and flexural strength of the composites. Further, development of toughness and reasons for traditional use of the equal volumetric ratio of raw materials is also discussed.

Chapter-4 explains the results of technical verification on the popularity of off-white color pots in western Rajasthan as compared to the pots manufactured and imported from neighboring state of Gujarat. The discussion in this chapter also acknowledges the potential of knowledge on pottery manufacturing and sintering and challenges of modern methods of cooling and storing water methods.

Chapter-5 deals with the discussion on manufacturing, dissemination, production, and testing of baked clays ceramic water filter using household manufacturing facility available at potter's community. The classification of composites in chapter 3 and ceramics upholding the significance of the science of equal volume fraction distinct material mixtures and recognition of their importance in sequential process of ceramic manufacture from composites is enumerated. The chapter includes detailed elaboration on manufacturing process management at a potter household and thus manufacturing frustum shape water filters by local potter community using traditional methods of pottery.

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